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ABSTRACT

This paper reviews research and opinions concerned with the lateralization of brain functions and cognitive development as described by Piaget. Optimal cognitive functioning in humans is a product of the complete development of interhemispheric communication in the brain. Growth spurts in brain development have been found to correlate closely with Piaget's developmental stages. The preoperational stage includes the progressive development of the neural fibers which connect the brain hemispheres, i.e., the corpus callosum (CC), and includes a brain growth spurt between the ages of 2 and 4. At this stage true lateralization of cognitive functions begins to occur as both hemispheres and the interhemispheric communication system continue to develop. Both right and left hemispheric developments can be seen in the stage of concrete operations. The development of the CC appears to be dependent upon its use and on the utilization of both hemispheres. A bias toward linear, logical thinking, or left hemisphere rationality, predominates in our educational system. This emphasis appears deficient insofar as hemisphere interaction has been associated with optimal cognitive functioning, increased creativity, self-actualization and mental health, as well as specific learning outcomes. Piagetian classroom practices for optimal development utilize both brain hemispheres. (RH)

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The Relationship Between Piagetian Cognitive Development and Cerebral Cognitive Asymmetry

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Abstract

We now know that most adult brains have two very differently functioning hemispheres. There appears to be a close relationship between the development of this hemispheric asymmetry of cognitive functions and cognitive development as described by Jean Piaget. This paper reviews those opinions and research studies that have addressed this issue directly, hypothesizes what the relationship might be, and discusses the implications for education resulting from these two important areas.

The Relationship Between Piagetian Cognitive Development and Cerebral Cognitive Asymmetry

That our brain has two minds, two very differently functioning hemispheres, is now well documented (Bogen, 1969a, 1969b; Dimond & Beaumont, 1974; Gazzaniga, 1970, 1975; Kinsbourne & Smith, 1974; McNeil & Hamre, 1974; Milner, 1971; Nebes, 1974; Ornstein, 1977; Schmitt & Worden, 1974; Segalowitz & Gruber, 1977; Sperry, 1973). In normal, right-handed adults the left hemisphere is specialized for verbal, logical, linear, and sequential tasks which are abstract and time related. It is the brain's language center for verbal and mathematical tasks. The right hemisphere is specialized for visual, spatial, metaphorical, and intuitive tasks. It processes nonverbal information and is responsible for visual imagery and imagination. The right hemisphere is mute but can comprehend simple language. For a further description of the different hemispheric functions, see Table 1.

Insert Table 1 about here

It is important to emphasize, however, that what most characterizes the differences in hemispheric functioning is not that they are specialized to work with different types of materials, but that each hemisphere has a

specialized cognitive style. The left hemisphere utilizes an analytical, logical mode for which words are an excellent tool, and the right uses a holistic, gestalt mode which happens to be particularly suited for spatial relations.

The purpose of this paper is to examine the relationship between this lateralization of cognitive functions and cognitive development as described by Jean Piaget. The paper will be divided into three sections. The first section will review those opinions and research studies that have addressed this issue directly. The second section will describe the characteristic cognitive abilities of each of Piaget's developmental stages and hypothesize what hemispheric processes might be occurring. The last section will discuss the implications for education resulting from the hemispheric asymmetry findings and relate them to the educational strategies resulting from Piagetian theory.

Review of the Literature

Bob Samples, a creative genius in the application of hemispheric functioning to learning and development, asserts that Piaget's developmental theory describes left hemispheric development only. In his brilliart book on an alternative way of thinking, The Metaphoric Mind (Samples, 1976), he says, "Piaget's constructs describe only the functions of the left cerebral hemisphere in

most humans" (p. 58). In another article, he emphasizes this again when he says, "At about age 12, most children enter the apex of logical conformity, the formal operations stage. He/she will have given up intuitive, analogic explanations for those that are factual and explicit. In other words, the student will have become left hemisphere dominant" (Samples, 1977, p. 689). It has been shown that language is predominantly a left hemisphere function (Gazzaniga & Sperry, 1967; Liberman, 1972; Searleman, 1977), and Samples relates that to Piagetian development when he says, "The result is that to become expert in the logical manipulation that is necessary to engage in Piaget's formal operations stage, one must become expert in language use" (1977, p. 689).

Lawson and Wollman (1975) agree with Samples. They tested 82 right-handed children, ranging in age from 5.3 to 6.3 years, on four conservation tasks--number, substance, continuous quantity, and weight. The children were grouped into categories of right-eye dominant and left-eye dominant. Then the following four situations were constructed: (a) left-eye dominant children viewing the material with their left eye only (LL), (b) left-eye dominant children viewing the materials with their right eye only (LR), (c) right-eye dominant children viewing the material with their left eye only (RL), and (d) right-eye dominant children viewing the material with their right eye only (RR).

This design was based on the assumptions that visual input from the left eye will reach the left visual cortex before it reaches the right visual cortex (presumably because the neural pathways are shorter from the left eye to the left visual cortex than from the left eye to the right visual cortex), thereby giving the left hemisphere priority and vice versa, and that eye dominance is caused by hemisphere dominance.

They hypothesized that "the functioning of the brain's left hemisphere, because of its logical, verbal mode, facilitates conservation reasoning while functioning of the brain's right hemisphere, because of its nonverbal, spatial mode, inhibits conservation reasoning" (p. 3). Therefore, children in the LL group will demonstrate a greater frequency of conservation responses than children in the RR group. They further hypothesized that the LR and RL groups will demonstrate an intermediate frequency of responses.

This predicted sequence of LL > LR=RL > RR was found, and the LL and RR group differences were significant. They concluded that intellectual development in the Piagetian sense is largely a function of the left hemisphere's verbal and linear functioning and its ability to dominate the right hemisphere's more spatial and holistic mode of operation.

Another study by Dilling and others (1976) also

supports this theme, although somewhat less emphatically. They investigated the differences in hemispheric brain activity of concrete and formal operational persons. They had six concrete subjects and seven formal subjects do seven tasks while lateral EEG recordings were being made. The last three tasks they used were Piagetian tasks. These were conservation of volume, control of variables, and a logic problem. The final two tasks require formal operational thinking for a complete solution.

A summary of their results shows that formal persons were relatively more left hemispheric in their cognitive functioning than were concrete persons. This was especially true in the two formal tasks, control of variables and logic. They concluded that formal operational persons have more lateralized cognitive functioning than concrete operational persons.

Johnson (Note 1) disagrees with the idea that Piagetian development refers to the left hemisphere only. She hypothesizes that the key to cognitive development is interhemispheric communication, which is primarily a function of the corpus callosum. She states that "the desired developmental goal is the ability to recognize and use the mental mode best suited for a specific task, utilizing information stored in both hemispheres" (p. 6), and that at the cognitive apex, the formal operations stage, the corpus callosum must be capable of rapid communication.

Johnson has support in a study done by Olson (1977) who studied gifted children to determine if they were right visual field (RVF) dominant, implying the left hemisphere, or left visual field (LVF) dominant, implying the right hemisphere. She found that gifted children who demonstrated formal operational thought used their RVF (left hemisphere) for verbal questions and their LVF (right hemisphere) for spatial questions. This is consistent with other research findings. What was significant, however, was that with students who were at the concrete operational stage, this sorting did not occur. They used their RVF predominantly on all tasks. The implication of her findings is that it is the efficient use of both hemispheres that determines formal operational thought, which agrees with Johnson's hypothesis.

In the most complete study on this topic done to date, Kraft (1976) lends strong support to the theory that Piagetian development includes both hemispheres and the corpus callosum. She investigated lateral asymmetry in children's hemispheric brain functioning during performance of Piagetian and curriculum related tasks by measuring lateral EEG activity during the performance of those tasks. Her subjects were 18 right-handed children between the ages of 6 and 8. The Piagetian tasks that were used were two conservation tasks and two temporal (time-related) tasks.

After a complex analysis of the EEG data, she concluded that the Piagetian tasks which had initial visuo-spatial components during the stimulus period tended to elicit right hemispheric activity during that period. If that task had verbal or logical components during the subsequent response period, then left hemispheric activity tended to be elicited. However, high performers on these tasks tended to show a greater proportion of right hemispheric activity during the response period than low performers, indicating that the verbal left hemisphere of the high performers utilized greater ability to tap the visuo-spatial right hemisphere's knowledge about the stimulus. She then suggests that Piagetian tasks are behavioral components of interhemispheric communication and selective inhibition and further, that the ontogeny of Piagetian stages is a behavioral index of maturing neural fibers which facilitate these processes.

This review clearly shows the division of thought on this subject. The two prevalent theories, that Piagetian development refers to the left hemisphere only and that Piagetian development refers to bihemispheric development and the development of an interhemispheric communication system, both have support. There is not enough evidence, however, to lead to a decisive conclusion in favor of either theory. Obviously, more research needs to be done.

Although it does not help resolve the issue, there is one other research finding that needs to be mentioned in this review. Epstein (1974a, 1974b, 1978) has found that there are growth spurts during brain development (which he hypothesizes to be periods of maximum cognitive potential) and that these growth spurt intervals correlate closely with Piaget's developmental stages. These growth spurts occur primarily during the age intervals of 3 to 10 months and from 2 to 4, 6 to 8, 10 to 12 or 13, and 14 to 16 or 17 years of age. Except for the first and last intervals, the relationship with Piagetian stages is clear. The growth spurt from 2 to 4 coincides with the transition from sensorimotor to preoperational, the spurt from 6 to 8 coincides with the transition from preoperational to concrete operational, and the growth spurt from 10 to 12 or 13 coincides with the transition from concrete to formal operational. It has even been hypothesized by Arlin (1975) that there is a fifth Piagetian stage, which appears at about the predicted age of 14 to 16 or 17. Although I will not go into the many implications of this finding, it is important to note this neuroanatomical support for Piaget's theory. Hopefully, further research in this area will determine if these growth spurts are localized (e. g. left or right hemispheric) and shed some light on the issue we are addressing here.

A Comparison of Piagetian and Hemispheric Development

Piaget's theory outlines four major periods of mental development: sensory-motor, preoperational, concrete operational, and formal operational (Sund, 1976). He assigns approximate ages to these periods, but more important is understanding that the order of succession is a constant--each stage is necessary for the development of the following one--and that the stages are not static; a child progresses through them in a continuous manner.

The sensory-motor period lasts from birth until approximately 2 years of age. During this short time, a child makes tremendous cognitive gains, growing from a reflex dominated creature to a dynamic, reacting child.

During this same period, an important change is occurring within the structures of the brain. Hewitt (1962) has found that at birth the corpus callosum, the mass of neural fibers connecting the two hemispheres and responsible for intercommunication between them, is structurally and functionally incomplete, and that communication between the hemispheres does not start until around age 2. This means that during this period the child is functionally "split-brain" (Gazzaniga, 1970, pp. 131-134).

There are two prevalent theories about the structure of the brain at birth. One is that the hemispheres are functionally identical and have the same potential for

development (Lenneberg, 1967). The other is that the hemispheres are specialized at a very early age or preprogrammed from birth (Kinsbourne & Hiscock, 1978, pp. 214-220). What is important, however, is that if the infant is split-brained during the sensory-motor period, then each hemisphere is experiencing different input--the left hemisphere getting information from the right hand, right ear, and right visual field, and vice versa--and whether they are preprogrammed to develop differently or not, it is this difference in experience that facilitates the lateralization of cognitive functions.

What cognitive abilities make their appearance in the sensory-motor stage? The sensory-motor child learns to perceive and identify objects. He does not have language abilities but does recognize the names of objects. These abilities appear to be a combination of what are later identified as left and right hemispheric functions. This also applies to his acquisition of object permanence and the recognition of himself as an object.

Two abilities that appear that are later dominant in the right hemisphere are his rudimentary sense of direction and the realization that objects do not change in shape even though viewing them from different vantage points makes it appear that they do. These indicate a refinement of visuo-spatial abilities.

It is during this period that the beginning of linear, logical, left hemispheric reasoning makes its appearance. The sensory-motor child learns to perform simple experiments on objects to learn some of their properties, and demonstrates means-end activity. Near the end of the period he becomes aware of linear time--he recognizes sequence and duration of events. These abilities lead him into the preoperational period, which begins at approximately age 2 and lasts until around age 7.

During the preoperational period two important neurophysiological changes are taking place. One is that the corpus callosum becomes capable of intercommunication at around age 2 or 3, and completes the major part of its development at around age 6 or 7 (Yakovlev & Lecours, 1967). The other is the brain growth spurt that occurs between the ages of 2 and 4 which Epstein (1974a, 1974b, 1978) hypothesizes is a period of maximum cognitive growth potential.

The preoperational child can be described by the following three characteristics:

1. He is perception bound, indicating visuo-spatial dominance, which is a right hemispheric function.
2. He cannot think logically, which is a left hemispheric function.

3. He cannot perform operations that are dependent upon thinking linearly, analytically, sequentially, and causally, all of which are left hemispheric functions.

However, the most clearly observable behavioral change that occurs during this period is the development of language and verbal abilities, which are predominantly left hemispheric. So it is during this period that true lateralization of cognitive functions begins to occur. But development is not confined to the left hemisphere, as Samples (1976, 1977) has hypothesized. A look at the cognitive gains of this period will show that development is occurring also in the right hemisphere and in the interhemispheric communication system.

Several left hemispheric abilities, besides language and verbalization, show their early beginnings in the latter portion of this stage. The child develops what Sund (1976) calls semilogic, but it is limited to forward-direction thinking only. The preoperational child cannot think reversibly or reflectively. He cannot reason inductively or deductively, but does begin to reason transductively--from particular to particular. This often leads to faulty conclusions, but it is the beginning of reasoning sequentially and causally. The preoperational child also gains a better understanding of linear time, including short periods into the past and future.

The right hemisphere is also developing useful abilities during this period, the most important of which may be representational thought. This is dependent upon visual imagery--the ability to imagine an action, or series of actions, and the possible results. Piaget believes that this ability is fundamental to the development of more complex operational abilities. The preoperational child also develops a broadened concept of space and direction, increased ability to imagine and fantasize, and a greater sense of intuition, all right hemispheric functions.

It is important to note that it is during these years that left hemispheric abilities such as verbalization and reasoning are given great value while many right hemispheric abilities such as imagination and intuition are criticized. This is the beginning of a cultural and educational bias towards the left hemisphere, but it is not the fault of Piaget.

Remember, also, that during this period the hemispheres begin to communicate with each other. This means that they are developing a new ability--to use both hemispheres concurrently and supportively, and they are learning to distinguish the appropriate, or most efficient, use of each.

At approximately age 7 the child enters the concrete operational stage, which lasts until age 11 or 12. The transition into this period is also marked by a brain

growth spurt (Epstein, 1974a, 1974b, 1978). During this period, children's thoughts are restricted to what they encounter in direct experience and the actions they can perform with concrete objects. They do, however, develop many mental operations during these crucial years.

The concrete operational child is no longer fooled by perceptual differences as he was in the preoperational period. He now uses his mind to think rationally (left hemispheric) instead of relying solely on perception (right hemispheric), which leads to the attainment of conservation of various types. This occurs sequentially from ages 6 or 7 to ages 11 or 12, beginning with conservation of substance and ending with conservation of volume. This sequence is an observable indicator of increasing left hemispheric development. It does not mean, however, that the right hemisphere is becoming increasingly undeveloped or unused. The left hemisphere is still operating on right hemispheric information, and it is this increase in intercommunication and cooperation that leads to increased logical reasoning ability.

Other cognitive abilities appearing during this period are the understanding of number and the ability to perform mathematical operations, the ability to classify objects, and a better understanding of linear time, all predominantly left hemispheric functions.

During this period the concrete operational child also gains an understanding of part-whole relationships, which has been shown by Nebes (1971) to be a right hemispheric function. He also develops increased right hemispheric ability for mental imagery, imagination, and intuition. The extent to which these abilities are developed, however, is dependent upon their use and encouragement, and too often this does not occur.

The concrete operational child also has an increased understanding of space, especially geographical space. Nebes (1971) describes this as a right hemispheric function when he says, "It is the right cerebral cortex which is responsible for forming from the incomplete information provided by our senses the spatial and cognitive map of our surroundings" (p. 10).

Piaget believes a major achievement of the concrete stage is the discovering of how concepts are interrelated. This ability to synthesize information is also a right hemispheric ability. So despite the emphasis on left hemispheric cognitive gains during this stage, the right hemisphere is also developing--gaining new abilities and refining old ones.

Let me again emphasize the importance of increased interhemispheric communication for the development of these higher level operational abilities. The corpus

callosum is mostly developed by age 6 and fully developed by age 10 (Yakovlev & Lecours, 1967). Its potential has not been demonstrated, but it does seem clear that its development is dependent upon its use and this is dependent upon the utilization of both hemispheres. This bilateral utilization occurs very infrequently in our education system, which may account for the fact that fewer than 50% of the adults in the United States ever reach the formal operations stage of thinking (Sund, 1976, pp. 75-80).

If a child's development has been fully allowed and facilitated through the concrete operations stage, he will then proceed into the formal operational period. This generally occurs around age 11, which coincides with a brain growth spurt between the ages of 10 and 12 (Epstein, 1974a, 1974b, 1978) and the completion of the development of the corpus callosum at around age 10 (Yakovlev & Lecours, 1967). This transition into the formal operations stage can occur later than age 11, however, and, as was mentioned previously, may not occur at all.

The formal operational period is characterized by systematic and logically complex reasoning processes. Operations are no longer restricted to concrete objects but can be performed on other operations as well.

Due to the left hemisphere's linear, analytical, logical cognitive processing mode, the following formal operational abilities can be characterized as predominantly left hemispheric:

1. Hypothetical-deductive thinking: it therefore follows that ...
2. Propositional thinking: it is either this or that
3. Reflexive thinking: evaluating thinking processes
4. Abstract thinking: no longer requires objects
5. Devising, testing, and controlling one variable at a time
6. Using proportions and ratios
7. Understanding and using probability
8. Constructing a hierarchical classification system
9. Understanding linear time

There are fewer obviously right hemispheric abilities: imagining idealistically, conceptual thinking, and a broadening spatial concept; and there are a few that clearly utilize both hemispheres: mentally representing operations (right) and operating on them (left), performing combinational logic--combining elements (right) or eliminating elements (left) that do or do not affect a situation, and creating theories, described as bihemispheric by Coulter (Note 2).

It would be faulty to conclude, however, that formal thinking is a function of the left hemisphere only based on the fact that there are numerically more predominantly left hemispheric functions listed. As I have sought to show throughout the developmental sequence, qualitatively superior thinking requires the efficient use of two fully developed hemispheres and a fully developed interhemispheric communication system. As Kraft (1976) noted, superior thinkers are more able to use the visuo-spatial knowledge of the right hemisphere when performing left hemispheric operations. Samples (1976) sums it up beautifully when he says, "Equilibrium ... the balance between the rational and metaphoric minds, the quiet synergy that exists when there is no attitudinal prejudice either toward or away from either of the natural functions of the mind....Our minds are designed to reason as well as to dream" (p. 190).

Implications for Education

Western civilization in general and the United States in particular have long been prejudiced in favor of left hemispheric thinking (Fischer & Rhead, 1974; Galin, 1976; Rennels, 1976; Samples, 1977). Fischer & Rhead (1974) state emphatically that "the scientific and technological world-view of our time contains a strong bias toward the rational thought process characteristic of the 'Aristotelian'

or left hemisphere of the brain. We further hold that this bias in favor of left hemisphere rationality has resulted in neglect of the intuitive, holistic cognitive processes of the right hemisphere" (p. 50). They go on to say that "right hemispheric underdevelopment, due to deprivation, may account for many of the social and individual symptoms currently observed in technologically over-developed countries" (p. 54).

If our society is predominantly left hemispheric, then so too should be our education system, and there is overwhelming support that it is (Bogen, 1975; Brandwein & Ornstein, 1977; Fischer & Rhead, 1974; Galin, 1976; Hunter, 1976; Rennels, 1976; Samples, 1975a, 1975b, 1977). A close look at both curricula and teaching methods at any level of our education system will reveal this bias towards linear, logical thinking.

The crucial question, however, is if there is anything wrong with a left hemispheric education system; or a left hemispheric individual. Are two hemispheres better than one? The answer seems to be an unqualified yes (Brandwein & Ornstein, 1977; Rennels, 1976; Samples, 1975a, 1975b, 1977). Hemispheric symmetry has been credited with optimal cognitive functioning (Fischer & Rhead, 1974), increased creativity (Coulter, Note 2), self-actualization (Samples, 1975b), and mental health (Galin, 1974).

After years of research into the learning process, Samples (1977) concludes, "After several years of testing and evaluating, we came to the realization that when one invites both mind functions into equal partnership, three things characterize the learning ecology: 1) higher feelings of self-confidence, self-esteem, and compassion; 2) wider exploration of traditional content subjects and skills; 3) higher levels of creative invention in content and skills" (pp. 689-690).

How does this apparent need for the utilization of both hemispheres in the learning process relate to Piagetian theory? In the first section I reviewed several research studies and opinions supporting the idea that qualitatively superior thinking is dependent upon the efficient use of both hemispheres and intercommunication between them (Kraft, 1976; Olson, 1977; Johnson, Note 1). In the second section I sought to show that Piaget's developmental sequence is describing the development of both hemispheres and the key to intercommunication, the corpus callosum. Further support for this theme can be found by showing that the implications for teaching to optimize Piagetian development contain components designed to utilize both hemispheres.

Sund (1976) states that assimilation and accomodation are dependent upon internalization of information, and that

this can only occur when the information is acted upon by the learner. He cites the following example:

> An eighth grade science teacher may have students developing a conceptual understanding about a cold air front moving in over an area, and then ask the children to construct a metaphor or analogy to describe what happens. (p. 65)

Metaphor and analogy are right hemispheric functions. This, then, is clearly an attempt to reinforce left hemispheric learning with right hemispheric learning.

One of the most consistent messages to teachers from Piagetian theory is the need for the abundant use of concrete materials and hands-on experiences (Sund, 1976). Even with formal operational persons, a new concept should first be introduced concretely. The use of concrete objects involves the right hemisphere, particularly adept at perception, or both hemispheres when both hands are used for sensory input.

Piagetian theory also stresses discovery learning (Sund, 1976). This involves inquiry, creativity, synthesis, intuition, and many other right hemispheric functions as well as analysis, logical and linear reasoning, and many left hemispheric functions. In fact, student directed discovery learning frees the learner to use whichever cognitive mode or modes he wishes, leading to his acquiring

the ability to recognize and use the most efficient one, which coincides with Johnson's (Note 1) definition of formal thinking.

Role playing as a learning experience is also encouraged in a Piagetian learning environment. Samples (1975b) talks about a similar situation when he encourages the use of instant skits to utilize some nonverbal, intuitive learning processes.

This comparison could go on, but I hope it is clear that a Piagetian classroom at any level is one making extensive use of many modes of learning, including those that are characterized by left or right hemispheric cognitive processes or require the efficient use of both. Piaget himself has said, "The principal goal of education is to create men who are capable of doing new things, not simply of repeating what other generations have done ... men who are creative, inventive, and discoverers [hemispheric symmetry]" (Ginsburg & Opper, 1969, pp. 231-232).

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2. Coulter, D. J. The other side of learning. Unpublished manuscript, University of Northern Colorado, 1978.

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Table 1

Hemispheric Processes

Left	Right
analytic	synthetic
verbal	visuo-spatial
linear	holistic
rational	intuitive
logical	analogical
propositional	appositional
abstract	imaginative
sequential	simultaneous
convergent	divergent
deductive	inductive
temporally linear	temporally cyclic
symbolic	visually imaginative
exclusive	inclusive
singular	multiple
causal	coincidental
realistic	idealistic
mathematical	artistic
manic	depressive